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RECENT REINFORCEMENT-SCHEDULE RESEARCH AND APPLIED BEHAVIOR ANALYSIS

KENNON A. LATTAL AND NANCY A. NEEF

WEST VIRGINIA UNIVERSITY AND
UNIVERSITY OF PENNSYLVANIA

Reinforcement schedules are considered in relation to applied behavior analysis by examining several recent laboratory experiments with humans and other animals. The experiments are drawn from three areas of contemporary schedule research: behavioral history effects on schedule performance, the role of instructions in schedule performance of humans, and dynamic schedules of reinforcement. All of the experiments are discussed in relation to the role of behavioral history in current schedule performance. The paper concludes by extracting from the experiments some more general issues concerning reinforcement schedules in applied research and practice.

DESCRIPTORS: reinforcement schedules, behavioral history, verbal behavior, dynamic schedules, application of basic processes

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We selected three areas of contemporary reinforcement-schedule research as the topic of our article for this series on the potential applications of recent developments in the experimental analysis of behavior: the effects of behavioral history on reinforcement schedule performance, the role of instructions in schedule performance of humans, and dynamic schedules of reinforcement. These areas share several interesting similarities, beyond representing some current research directions in schedules of reinforcement. First, all of the research bears directly on human behavior, which is a strong trend in the experimental analysis of behavior (Hyten & Reilly, 1992). Even the nonhuman animal (hereafter, animal) experiments on behavioral history that we discuss are rooted in earlier investigations of behavioral history effects with humans. Second, the research in each area illustrates how the immediate schedule circumstances interact with other variables to control behavior. These variables may be thought of broadly as historical ones, whether they involve what happened on the preceding cycle in the case of dynamic schedules, in preceding conditions in the case of history effects, or in the person's verbal repertoire, which often is considered another kind of history. Third, the research in each area comments on and qualifies the reinforcement process, albeit in different ways.

We begin by discussing the definitions and roles of reinforcement schedules in contemporary behavior analysis. This is followed by a review of some representative experiments in each area mentioned above and a discussion of their potential relevance for applied behavior analysis. We conclude with some more general issues concerning basic research involving schedules of reinforcement in relation to applied behavior analysis.

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Reprints can be obtained from Kennon A. Lattal, Department of Psychology, West Virginia University, Morgantown, West Virginia 26506-6040 (E-mail: lattal@wvnvm.wvnet.edu) or from Nancy A. Neef, Graduate School of Education, University of Pennsylvania, 3700 Walnut Street, Philadelphia, Pennsylvania 19104-6216 (E-mail: nancyn@nwfs.gse.upenn.edu).

REINFORCEMENT SCHEDULES IN BEHAVIOR ANALYSIS

Reinforcement schedules have been defined as prescriptions for arranging reinforcers in time and in relation to responses, as the rules used to present reinforcing stimuli (Zeiler, 1977), or as "specification(s) of the criteria by which responses become eligible to produce reinforcers" (Catania, 1992, p. 394). Such definitions are useful in specifying the form or structure of the schedule, but they fall short in other domains. First, they are mute on the dynamic interplay between the initial prescription or rule and subsequent behavior. This dynamic nature of at least some reinforcement schedules affects the subsequent arrangement between time, responses, and reinforcers that in turn leads to changes in performance. Second, they do not consider how schedule-controlled performance may be tempered by such factors as prior history or the operation of other contextual factors such as, in the case of humans, instructions that may either compete with or complement the rules specified by the schedule. Third, the definitions understate the role of schedules in natural settings where they also may be presumed to operate, but not always in a manner prescribed or imposed by an agent or specified by an a priori rule, as the definitions imply.

The ubiquity of schedules has made them a focal point of behavior analysis. They sometimes have been labeled the "amino acids of behavior" and often have been discussed as fundamental determinants of behavior (Morse & Kelleher, 1977). Reinforcement schedules are central in the experimental analysis of behavior because of what can be learned about the reinforcement process from them *and* because they serve as useful baselines for the study of other behavioral processes (Zeiler, 1984). Reinforcement schedules serve similar purposes in applied behavior analysis and also, either directly or indirectly, are embedded in most treatment programs.

CURRENT SCHEDULE PERFORMANCE AND SCHEDULE HISTORY

An assumption of behavior analysis is that operant behavior is controlled by current reinforcement schedules. Recent investigations with both animal and human subjects have systematically explored how previous experiences also influence current schedule-controlled behavior. The experiments illustrate techniques for establishing functional relations between explicitly arranged past experiences, offer a broader context for discussing reinforcement schedule performance, and raise important issues for applied behavior analysts concerning how historical variables are conceptualized and studied in relation to applied problems.

Historical variables have been examined in basic research by establishing different baseline histories of responding under separate schedules and evaluating subsequent performance under a common third schedule as a function of prior schedule experience. For example, Freeman and Lattal (1992) examined behavioral history effects in three experiments with pigeons. In the first experiment, subjects initially were exposed daily to a fixed-ratio (FR) schedule during one session and to a differential-reinforcement-of-low-rate (DRL) schedule during the other session, each under different stimulus conditions. Each schedule was presented for 50 or more sessions, and established a history of responding at a rate that was about 4.5 times higher under the FR than under the DRL schedule. Subsequently, identical fixed-interval (FI) schedules were implemented under the respective stimulus conditions during both of the sessions for 60 days. Response rates in the former FR condition remained higher than response rates in the former DRL condition, and they tended to converge only after prolonged (approximately 15 to 40 sessions) exposure to the FI schedule. Similar results were obtained in a second experiment that examined the effects of high-rate (FR schedule) and low-rate (DRL schedule) histories of responding on subsequent performance under a variable-interval (VI) schedule of reinforcement, except that the effects of history were not as persistent. These results were replicated in a third experiment using a multiple schedule to generate high and low response rates within individual baseline sessions.

These studies demonstrated that if behavior has been established under stimulus control in the past, then that past schedule performance affects current responding in the presence of the stimuli. They also suggest that certain histories of reinforcement can be relatively persistent (e.g., DRL on subsequent FI performance). Does an intervening history mitigate the persistence in behavior of more remote histories? LeFrancois and Metzger (1993) compared rates of bar presses by two groups of rats under FI schedules. For both groups, responses first were conditioned under a DRL schedule, but for one group, exposure to an FR schedule preceded the FI schedule. Performance under the FI schedule was affected by immediate history, and DRL schedule histories did not affect FI performance for subjects with an intervening FR schedule history.

Humans past the age of 5 or 6 years often differ from animals in patterns of responses and control by schedules of reinforcement. For example, whereas the scalloped or "break-and-run" pattern predicted by FI schedules readily occurs with rats and pigeons (i.e., postreinforcement pause followed by positively accelerated response rates), human performance, particularly human performance that is instructed (e.g., Catania, Matthews, & Shimoff, 1982), is resistant to control by the temporal variables that are implicit in those schedules. Thus, one could expect some history effects (e.g., those reported by Freeman & Lattal, 1992) to be even more persistent or to manifest differently with humans. This in turn has led to other investigations of variables related to behavioral history that might account for such differences.

For example, it has been hypothesized that, for humans, variable-ratio (VR) schedules that generate high-rate responding could interfere with subsequent FI performance (Wanchisen, Tatham, & Mooney, 1989); however, the results of a study by Baron and Leinenweber (1995) suggested that such a VR history does not by itself account for FI performance differences between humans and other animals. That study examined performance of 18 rats under an FI 30-s schedule, half of whom had a conditioning history of high-rate responding under single or compound VR schedules. As in previous studies, the high response rates initially established in the rats exposed to VR schedules progressively diminished with continued exposure to the FI schedule. Of particular note, however, was that the pattern of responding within each FI was similar for subjects with and without a VR history. That is, subjects with and without a prior VR history showed similar development of the characteristic FI scallop and postreinforcement pauses that are indicative of temporal control by FI schedules. Thus, although history effects for rats with prior exposure to VR schedules were evident in high overall response rates under the FI schedule, within-interval response rates were similar to those of rats without a VR history. Regardless of history, then, rats' responding was controlled by the schedule in a way that is not always characteristic of adult human performance.

That a history of responding established under certain schedules affects current performance under a different reinforcement schedule for some period of time after the original conditions have changed has also been observed in applied studies with human subjects. For example, in a study of concurrent schedule reinforcement of academic behavior, Mace, Neef, Shade, and Mauro (1994) reported that "changes in the concurrent VI schedules failed to generate patterns of time allocation that matched the relative rates of reinforcement. Instead subjects generally tended to persist in their allocation patterns of the previous schedule condition" (p. 593).

Considering that the control of current schedule performance by past experiences appears to be a robust finding in basic research, it is somewhat surprising that the residual or carryover effects of prior experiences have not been observed more often in applied studies. It may be that carryover effects are more common than it would appear from the literature. For example, because multiple baseline and reversal designs that are common in applied research require immediate changes in behavior to demonstrate experimental control, studies in which behavior patterns persist from one condition to the next may not be submitted, or may be rejected, for publication.

Another possibility for the absence of history effects in applied studies is that changes in independent variables in these studies are often correlated with unique discriminative stimuli, which may mitigate the effects of behavioral history. This is supported by the results of studies by Freeman and Lattal (1992) indicating stimulus control of history effects, and by Hanna, Blackman, and Todorov (1992) showing that discriminated responding following changes in concurrent VI schedules occurred sooner in pigeons when each schedule was uniquely correlated with a discriminative stimulus (although see Mace et al., 1994, for an exception).

The extent to which history effects persist with humans cannot be predicted with certainty from those involving animals, as the results of Baron and Leinenweber's (1995) experiment illustrate. Perone, Galizio, and Baron (1988) discussed a number of differences between human and animal studies that may contribute to the differences in schedule performance as a function of schedule history. Specifically, in the case of differences in behavioral history effects, unlike the animal subjects' relatively simple and brief (e.g., 2 months or less) "simulated" histories, the behaviors of individuals treated by applied behavior analysts often have a history of many years' duration. The duration of a history might affect its persistence and may, for example, partially account for Lovaas' finding that the success of even prolonged intensive treatment for autism was related to the age of the child (Lovaas, 1993).

The results of LeFrancois and Metzger (1993) indicating that current performance is affected more by immediate history than by remote history have implications for applied research on functional analysis. In a sense, functional analyses involve efforts to determine the effects of immediate history by identifying the contingencies that maintain current responding. But doing so involves implementing contingencies and schedules of reinforcement that also create immediate histories for those behaviors. It is possible that the behaviors measured may come to be controlled more by the intervening histories arranged by the functional analysis than by the histories the functional analysis is designed to assess, especially if the analysis is prolonged.

Although the above studies indicate the control of current performance by previous schedules, they also demonstrate the diminishment of this control as experience under other schedules increases. History effects therefore can be conceptualized as transition states (Sidman, 1960). Indeed, the assumption that history effects, for the most part, will not persist indefinitely as behavior adapts to the present environment is the raison d'être for applied behavior analysis. It underlies our successes as well as our treatment failures such as relapse (Lerman, Iwata, Smith, Zarcone, & Vollmer, 1994).

Paradoxically, applied behavior analysts have regarded the role of behavioral history as both paramount and irrelevant. On the one hand, a tenet of behavior analysis is that history profoundly affects human behavior. In fact, it could be argued that for applied behavior analysts, arranging conditions to alter subsequent behavior is itself a matter, and goal, of generating a different history that will produce durable changes in the targeted behavior. On the other hand, until the development of functional analysis methods (Iwata, Dorsey, Slifer, Bauman, & Richman, 1982/1994), behavior analysts generally disregarded the historical conditions under which behavior developed. The relative lack of emphasis on the history that subjects bring to the situation is, in part, what distinguishes our field (e.g., from psychoanalytic models). One reason was practical: We can never know with certainty the history that led to the development of a particular problem behavior because we were not able to observe it (nor, obviously, to change it). We therefore relegated history to the role of an inevitable source of behavior variability, recognizing that "any difference in behavior will always be subject to interpretation as a product of some currently unknowable fluctuation in those unknown variables" (Baer, 1977, p. 168).

Another reason for disregarding behavioral history was a belief that history is irrelevant, either because the problem behavior, when we encounter it, might be affected by different conditions than those that contributed to its development, or because the arrangement of different conditions (immediate or proximal history) can override the effects of prior conditions (remote or distal history). As noted by Iwata et al. (1982/1994), "behavioral researchers and clinicians generally have dismissed the importance of etiology, since the conditions that are necessary to develop or maintain a response may be totally unrelated to the conditions that are sufficient to alter or eliminate it" (p. 198). It may be inconsistent or arbitrary to assume, however, that the relevance of history depends on whether or not we have arranged it. For example, sometimes we seek to establish a history that will render a desired behavior insensitive to immediate contingencies (as implied by the definition of generalization) so that it will be maintained in the natural environment. If we can arrange treatment conditions for desirable behavior to persist in the presence of disruptive events, then we also must appreciate that other conditions in the natural environment create a history in which problem behavior is resistant to change by our treatment conditions. By understanding how and under what conditions history affects schedule-controlled behavior, applied behavior analysts may be able to design interventions that mitigate or optimize those influences.

HUMAN VERBAL BEHAVIOR AND SCHEDULE PERFORMANCE

The studies just discussed illustrate that schedule performance is not determined exclusively by contemporary requirements for reinforcement. Human schedule performance also may be affected by typically long-standing histories of verbal behavior.

Hackenberg and Joker (1994) examined choices of adult humans when the correspondence between instructions and contingencies was made progressively less accurate by gradual shifts in the schedule of reinforcement. The purposes of their investigation were to examine instructional control under conflicting schedule requirements, the transition from instructional to schedule control, and the effects of a history of inaccurate instructions on compliance. The procedure involved presenting two different stimuli on a computer screen, one of which was associated with a fixed-time (FT) schedule and the other with a progressive-time (PT) schedule. Neither schedule required a response; the reinforcers were simply delivered at the end of the scheduled time period. After each successive reinforcer, subjects selected one or the other schedule, which then remained in effect throughout that trial. If a subject initially selected the stimulus associated with the PT schedule, a point was delivered immediately (0 s), and each successive choice of the PT schedule gradually increased the time to point delivery in fixed increments. If a subject initially selected the stimulus associated with the FT schedule, a point was delivered after 60 s and the PT schedule was reset to 0 s.

Subjects were given the same set of instructions throughout the experiment. Under the first experimental condition, the instructions accurately characterized the sequence of PT and FT choices that would produce the most reinforcement (i.e., the schedule and the instructions were identical). The size of the increments (step size) in the PT schedule was altered gradually across successive experimental conditions (in ascending and then descending order), such that the same instructions gradually became less (and then more) accurate in describing the optimal choice sequence. This unique procedure permitted examination of the transition from instructional to schedule control on a continuum of changing stimulus conditions, and examination of schedule control as a function of history.

Instructional control was established quickly in the first condition, in which instructions accurately described the schedules. However, conformity with instructions necessarily constrained the range of behavior (choice patterns), thereby both precluding contact with changes in the schedule and reducing subsequent control of responding. Choices continued to be controlled by instructions as the PT step size increased across several experimental conditions. As the instructions became progressively more inaccurate, however, choice patterns became more variable and produced more reinforcement, resulting in an abrupt transition from instructional to schedule control. The extent to which choices were controlled by the schedule contingencies as PT step sizes decreased (in the descending sequence) varied according to the point at which instructional control first broke down in the ascending sequence, suggesting that the history of consequences for following inaccurate instructions can have enduring effects on behavior.

The schedules in Hackenberg and Joker's (1994) experiment are analogous to many situations in the natural environment in which conditions gradually change (e.g., the progression of an illness, potency of a drug, the economy) such that instructions from others (e.g., physicians, financial advisers) that initially described the schedule become progressively less accurate. Hackenberg and Joker's results suggest that the history and degree of correspondence between instructions and consequences of behavior may affect the extent to which choices are determined by those changing conditions or continue to be controlled by instructions. In some situations, instructional control and weak control by changing schedule conditions are desirable because they increase the probability that a response will persist despite short-term punishers, extinction, or increasing work requirements (e.g., a physician's instructions when a medical program takes time to work). In other situations, control by instructions is maladaptive (albeit not always for the person giving them). Scam artists, for example, strengthen instructional control by initially arranging consequences that support their instructions (such as ensuring that the victim receives "profits" for a period of time) so that instructions will continue to control escalated investments in a bogus operation in which the effectiveness of the instructions depends on the victim's behavior becoming insensitive to the changing consequences (e.g., when the profits no longer arrive).

One direct implication of Hackenberg and Joker's (1994) findings for applied behavior analysts involves interventions to decrease noncompliance, one of the most pervasive childhood behavior problems (e.g., Neef, Shafer, Egel, Cataldo, & Parrish, 1983; Parrish, Cataldo, Kolko, Neef, & Egel, 1986). Establishing a history of following adult instructions may also have the disadvantage of reducing the direct schedule control of the behavior of children. For example, Parrish et al. (1986) found that reinforcing compliant behavior produced collateral reductions in inappropriate behavior (e.g., aggression, disruption) for which there were no scheduled consequences. Similarly, Neef et al. (1983) demonstrated that reinforcing compliance to a subset of instructions increased compliance with instructions of similar types of requests ("do" or "don't") that were not reinforced. The demonstration of generalized response classes (i.e., that reinforcement of instruction following had collateral effects on unreinforced behaviors) in both of these studies necessarily also shows that the unreinforced members were not controlled by the reinforcement schedule. Although these particular results had obvious advantages, such histories might also have long-term disadvantages if they produce rigid rule following that is not regulated by environmental contingencies.

Such rigidity effects were demonstrated in a recent study by Wulfert, Greenway, Farkas, Hayes, and Dougher (1994) on the effects of instructional histories and measures of behavioral rigidity on sensitivity to schedule contingencies. In the first experiment, the responding of subjects who were given accurate, specific instructions under a multiple DRL FR schedule of reinforcement showed more persistence when the condition was changed to extinction than did the responding of subjects who were not given specific instructions. Persistence was most pronounced for subjects who previously had been classified as "rigid."

In a second experiment, subjects were given accurate, specific instructions with an FR schedule in effect. When the schedule was changed to DRL, half of the subjects were instructed accurately and the other half were instructed inaccurately. All subjects who had been given accurate instructions responded accordingly. When instructions were inaccurate, all subjects initially responded according to the instructions (which described the previous FR schedule), but the subjects who had previously been characterized as rigid persisted in this pattern of behavior; responses of most of the "nonrigid" subjects eventually conformed to the schedule.

Some recent research suggests that self-generated rules may control nonverbal behavior similarly to instructions from others (e.g., Rosenfarb, Newland, Brannon, & Howey, 1992). For example, in some preliminary work on matching by Neef and colleagues, a student whose completion of different sets of math problems was reinforced on a concurrent VI 30-s VI 60-s schedule devoted her time exclusively to one set of problems, saying, "I should finish what I start before doing something else." Obviously in many situations control of behavior by that rule (or the history that is reflected in the rule) would be adaptive in obtaining reinforcers that are associated with successful task completion. But because that rule competed with the optimal response strategy in this situation, her behavior could not come into contact with the programmed contingencies. Her exclusive responding to a single alternative that yielded a relatively low rate of reinforcement persisted over numerous sessions until adjunct procedures were added (e.g., modeling, count-down timers) that nonverbally described the contingencies. Similarly, the extent to which faulty or imprecise rules may have been generated by other subjects in studies on matching by Neef, Mace, and Shade (1993), Neef, Mace, Shea, and Shade (1992), and Mace et al. (1994) could have contributed to the initial lack of control of their responding by concurrent VI schedules until adjunct procedures were used to establish matching.

The effects of self-generated rules on schedule performance was also examined by Horne and Lowe (1993) in a series of six experiments with 30 adults. Because matching had been reported in a number of studies with humans by Bradshaw, Szabadi, and Bevan (1976, 1977, 1979), Horne and Lowe used a similar procedure. Two computer keys could be pressed for points (exchangeable for money) on concurrent VI schedules. On one key, six different-valued VI schedules were randomly rotated every 10 min separated by 5-min rest periods; responses to the other key were reinforced on the same VI schedule throughout. Each VI schedule was correlated with a different stimulus (e.g., geometric shape). At the end of each experiment, subjects completed a questionnaire asking them to describe the schedules that had been in effect and the factors that had influenced their choices. These performance rules then were compared to the subjects' schedule performance. The choices of only 13 of the 30 subjects conformed to the generalized matching equation and approximated the typically reported performance of animal subjects. Significantly, actual performance of 29 of the subjects corresponded closely to their descriptions of the performance rules they had generated, whether or not those rules accurately described the reinforcement schedules (see also Rosenfarb et al., 1992).

These data suggest that adult humans' own verbal behavior may influence their behavior in the presence of reinforcement schedules, although in other studies the relation between subjects' descriptions and accompanying verbal responses has been less clear (Hackenberg & Axtell, 1993; Jacobs & Hackenberg, 1996). The relation between verbal description and schedule performance may be represented as a continuum. On the one hand, it is likely that schedule performance influences the verbal description. On the other, schedules might control performance only indirectly, to the extent that they affect individuals' verbal behavior in the form of rules that govern behavior. This latter observation has interesting implications for treatment. For example, naturally existing reinforcement schedules are often ambiguous, and even in treatment settings it is difficult to arrange them with the consistency and precision that are characteristic of laboratory research. To the extent that individuals formulate and follow faulty rules, nonverbal behavior that is controlled by those rules may be maladaptive or restricted such that it does not come into contact with schedules that might lead to other rules. In counseling situations, for example, clients are often encouraged to articulate their covert verbal behavior so that inaccurate contingency descriptions can be observed and challenged; the therapist can then shape more appropriate performance rules or prompt clients to follow testable rules that will contact contingencies that support alternative behaviors.

Early applied research addressed the role of verbal behavior directly in relations between verbal and nonverbal correspondence (e.g., Deacon & Konarski, 1987; also see Israel, 1978, for a review) or indirectly in self-instruction training (Meichenbaum & Goodman, 1971). However, there have been few studies in *JABA* on the role of verbal behavior over the past decade. For the most part, behavior analysts have treated verbal behavior and pretreatment history similarly: Because neither history nor covert verbal behavior can be directly observed, and reports of those events cannot be presumed to be reliable or valid, these variables are often considered to be incidental to prediction and management of behavior. In fact, in a seminal article that continues to define our field, Baer, Wolf, and Risley (1968) stated that applied research

> usually studies what subjects can be brought to do rather than what they can be brought to say. . . . Accordingly, a subject's verbal description of his own nonverbal behavior usually would not be accepted as a measure of his actual behavior unless it were independently substantiated. Hence, there is little applied value in the demonstration that an impotent man can be made to say that he is no longer impotent. The relevant question is not what he can say, but what he can do. (p. 93)

Although the focus of behavior analysis appropriately remains on what an individual does, the research by Horne and Lowe (1993) and others (e.g., Catania et al., 1982; Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986) suggests that behavior analysts need to consider that "what subjects can be brought to do" may, in many situations, be a function of "what they can be brought to say." It seems that the analysis of verbal behavior in relation to reinforcement schedules may warrant a more central role in applied behavioral research.

DYNAMIC REINFORCEMENT SCHEDULES

Much of the research in the areas described above concerns the role of distal experiences, either those with previous reinforcement schedules or aspects of a history of rule following, on current schedule performance. The control of schedule performance by more contemporary, or proximal, events is more characteristic of behavior-analytic research.

Reinforcement schedules typically involve repetitive, basically static, arrangements whereby the same requirements for reinforcement are in effect on successive cycles. With an FR schedule, for example, after every reinforcer the same fixed response requirement is repeated. But even here, there may be an interaction between schedule performance at a given point in a session and subsequent performance in that session. For example, during an FR schedule, reinforcement rate is determined by response rate such that more rapid responding yields a higher rate of reinforcement than does lower rate responding. Similar relations have been described for other schedules (e.g., Baum, 1973, 1989; Nevin, 1984). Such effects may be considered on the same continuum as those in the previously cited studies of historical influence on schedule performance, the difference being the time scale over which the prior experience is measured. The interaction of humans' rules and schedules also illustrates dynamic schedule effects. For example, if a rule and the requirements of a schedule are in conflict, over time the subject's behavior may conform to the schedule even though it was initially controlled by the rule (Galizio, 1979). Self-generated rules, if and when they occur, might interact in a similar way with schedule-controlled behavior to change the latter from time to time. As the person's rules change, within or between sessions, behavior changes, which leads to further changes in the rules and so on.

Dynamic reinforcement schedules provide a procedure for explicitly studying the types of interactions suggested in the preceding paragraphs. With these dynamic schedules, the requirements for reinforcement change after each reinforcer, or some sequence of reinforcers, as a function of either an a priori algorithm or some aspect of the organism's previous performance on the schedule. Theoretically, such dynamic schedules are of interest because of the insights they may reveal into the adaptation of behavior to rapidly changing circumstances. They also may be of interest to applied behavior analysts because they represent an attempt by basic researchers to address complex situations without dissecting them into more elemental schedules. Such dissection in fluid, applied settings sometimes is undesirable, difficult, or even impossible. We note too that we do not wish to proliferate an already complex taxonomy of schedules. Thus, the distinctions that we describe below are only for didactic purposes. We do not propose these terms as substitutes for descriptions of schedules that we believe are adequate (e.g., Lattal, 1991).

Algorithm-Based Dynamic Schedules

One dynamic arrangement occurs when the requirements for reinforcement are changed according to an algorithm. When an algorithm is used, the requirements change independently of behavior. Progressive schedules of reinforcement involve systematic, gradually incrementing response requirements for reinforcement in the case of progressive-ratio (PR) schedules, or time between reinforcement availability for a response in the case of progressive-interval (PI) schedules. The most common algorithms for incrementing the schedule requirements are arithmetic (i.e., a constant amount is added to each successive interval) and geometric (i.e., each successive interval is increased by a constant proportion of the preceding one) progressions. Because the changes in schedule requirements occur after each reinforcer (or block of reinforcers) and do so without regard to the organism's behavior, they exemplify an algorithm-driven dynamic reinforcement schedule.

Dougherty, Cherek, and Roache (1994) investigated PI schedule performance of human subjects. Subjects were seated at a console and earned points by pushing a button according to a chained PI *t*-s FI 20-s schedule. In the presence of the letter A on the computer screen, the first response after *t* s on a button changed the stimulus on the screen to B, indicating that an FI 20-s schedule was in effect. The first response after 20 s was reinforced in the presence of B. The FI schedule remained in effect until five reinforcers (points on a counter that were exchangeable for money) were earned. At that time, the letter A reappeared on the screen and the PI *t*-s schedule was incremented. This A-B cycle repeated throughout each 1-hr session. The size of *t* was 20 s, 40 s, 80 s, or 160 s in different conditions of the experiment. Increments in *t* were made according to either geometric or arithmetic progressions in different conditions. Human PI performance was characterized by diminishing response rates and increasing postreinforcement pause durations as a function of progressively increasing interval requirements. Postreinforcement pauses tended to increase arithmetically under the arithmetic progressions and geometrically under the geometric ones. Under both types of progressions, response rates decreased across increasing PI requirements. These results were similar to those reported by Harzem (1969), with rats as subjects. In a second experiment, Dougherty et al. used PI schedules to assess temporal control of behavior in humans as a function of different doses of marijuana. The findings of that second study are less important to the present theme than the fact that the investigators first analyzed a schedule with unknown effects on human behavior and then were able to use the schedule to assess another behavioral process: temporal control under a drug.

In PR schedules, it is customary to continue increasing the ratio requirement for reinforcement until responding ceases for a preestablished time period (e.g., 10 min, but the actual duration varies from one experiment to another), described as the break point (but see also Thompson, 1972, and Keesey & Goldstein, 1968, for other criteria). Break points have not been studied with PI schedules, raising a question about how PR and PI schedules compare in terms of engendering response persistence. Lattal, Reilly, and Kohn (1996) compared PI and PR performance directly by yoking PR and PI schedules such that, in successive pairs of sessions, a PR schedule in one session was followed by a PI schedule with a matched (yoked) distribution of reinforcers to the PR schedule. In each of 4 birds in almost every pair of sessions, PI responding continued beyond the point at which the break point had been reached on the PR schedule.

A progressive reinforcement schedule can be likened to an applied setting in which the level of difficulty of material being taught increases independently of the subject's behavior, as when instructor-paced changes in material are used. That is, regardless of the individual student's performance, according to a specified set of rules, objectives, or plans (often based on some performance measure based on group averages or modes), the requirements for reinforcement (successful task completion) increase systematically. Such progressions occur in many educational systems, and it is not uncommon under these conditions for a student's performance to deteriorate as the difficulty level or work requirements increase. Conversely, the difficulty level may remain constant but the subject's performance improves over time. The traditional negatively accelerated learning curve expresses the latter relation.

Progressive-ratio schedules also have been used to assess response persistence (Stewart, 1975). For example, Hodos (1961) showed a correlation between food deprivation and the break point on PR schedules. Mace et al. (1988, 1990) have provided a valuable series of experiments and thoughtful conceptual analyses that have elucidated the issues surrounding the resistance of targeted behavior to change in applied settings. Performance on PR schedules could be a useful complement to other measures of resistance to change in applied settings.

Interactive Dynamic Schedules

Another dynamic schedule arrangement is one in which the requirements for upcoming reinforcers change directly as a function of the organism's current or past behavior. The last schedule described by Ferster and Skinner (1957) was an adjusting schedule in which the response requirement of a ratio schedule was increased or decreased after each reinforcer as a function of how long the animal paused before responding after each reinforcement. These adjusting procedures sometimes have been described as titration procedures (e.g., Lea, 1976; Weiss & Laties, 1959).

Hackenberg and Axtell (1993) used an interactive dynamic reinforcement schedule to study the control of human behavior by long- and short-term consequences. They provided human subjects with choices between a PI schedule and an FI schedule that also, in some conditions, reset the PI schedule to 0 s. We will limit our description to the first of their three experiments, because it contained the features critical to the present discussion and yielded findings that were replicated and elaborated on in the subsequent experiments. On each of a series of trials, subjects chose one of two schedules (the unchosen schedule at the start of each trial was rendered ineffective for the remainder of the trial), each correlated with a distinct stimulus on a computer monitor. All operant responses were made on a computer keyboard space bar and, according to the schedules described below, yielded points that could be exchanged for money. Each trial started immediately after the preceding reinforcer with the simultaneous presentation of a red and a blue stimulus on the monitor. The red stimulus was correlated with an FI schedule, and the blue stimulus was correlated with a PI schedule that increased by 5 s after each point was delivered on that schedule. In different phases of the experiment, the FI was 15, 30, or 60 s. Two conditions were compared in each phase. In a no-reset condition, "PI requirements were independent of FI choices, escalating with successive PI choices" (Hackenberg & Axtell, 1993, p. 448). In a reset condition, choices of the FI schedule allowed a point to be produced by the operant response and reset the PI schedule to 0 s.

All but 1 subject switched between the schedules more frequently during the reset than during the no-reset condition. During the reset conditions, the subjects switched more frequently between the schedules when the FI value was shorter. Hackenberg and Axtell (1993) then asked whether the switching patterns were better predicted by taking into account only the immediately preceding PI interval, or whether they were better predicted by taking into account some aggregate of previous PI intervals. This was done by comparing the data to predictions derived from an optimality model (Charnov, 1976) and from a model based on the cumulative effects of one or more delays (PIs) to reinforcement. Based on these comparisons, they concluded that choice in diminishing returns situations (i.e., PI schedules) is determined by an aggregate of reinforcers in time over multiple trials, and not only by the immediately preceding PI value.

The shaping of a response through the differential reinforcement of successive approximations is a simpler example of a dynamic interactive schedule. Shaping involves systematic and progressive changes in the requirements for reinforcement as the subject meets successive behavioral objectives in relation to the target behavior. As the behavior more and less closely approximates the target response, the conditions necessary for reinforcement are adjusted. Thus, the subject's behavior alters the scheduling of reinforcers. The optimal relation between behavior and changing requirements for reinforcement (i.e., the schedule) during shaping has been a matter of considerable speculation but limited experimentation.

There is general agreement that the contingencies should be changed "gradually," but the shaping of new behavior largely remains an art. One exception to this latter observation is the work of Eckerman, Hienz, Stern, and Kowlowitz (1980), who quantified the shaping process and suggested that large, rapidly changing requirements for reinforcement led to the fastest shaping of a key-peck response of a pigeon to a particular location on a 10-in. wide response strip. Similar conclusions about the dynamic changes in shaping have been reached by Platt and his colleagues (e.g., Alleman & Platt, 1973; Kuch & Platt, 1976) in the shaping of interresponse times. Galbicka (1994) recently discussed some of the applied implications of Platt's shaping procedures.

The control of human behavior by long- and short-term consequences is another example of an interactive dynamic schedule, in that what a person does in the present may either positively or negatively affect future reinforcers. In Hackenberg and Axtell's (1993) experiment, the value of the PI schedule, and the subsequent overall rate of reinforcement, depended on the choices of either of two schedules over trials. Applied behavior analysis historically has emphasized the immediate consequences of behavior, but further development of the type of analysis and theory derived from Hackenberg and Axtell's analysis of a dynamic interactive schedule illustrates how one might conceptualize and assess the effects of longer term consequences (e.g., reinforcement rate over extended time periods) on both individual and group (systems) behavior.

In terms of individual behavior, one example, which has been of considerable controversy among applied behavior analysts, is the use of aversive (shock) procedures as a means of controlling self-injurious behavior (e.g., Iwata, 1988). Some have argued that the short-term benefits of reduced maladaptive behavior are not compensated for by the long-term negative effects of shock on the child. Although Hackenberg and Axtell's (1993) study of dynamic reinforcement schedules obviously does not bear directly on this issue, it offers a framework for placing the problem of competing outcomes of individual behavior or individual treatment programs on a continuum with other problems that involve the analysis of short- and long-term consequences.

The same framework described above can be useful in behavior-analytic applications involving aggregates of people. In a business, for example, changing to a new system for providing a service may produce short-term losses of revenue that result from the time that must be devoted to employee training, but these losses may be more than compensated for in the long run by having employees who are better trained to deliver the services offered by the business.

It is perhaps too much of a stretch to claim that experiments like that of Hackenberg and Axtell (1993) are precisely analogous to the complex examples described in the preceding two paragraphs; however, their experiment, and others related to it, are valuable in providing a bridge between applied behavior analysts and basic researchers that allows the use of similar descriptions and techniques to account for human behavior through reinforcement schedule analyses.

CONCLUDING COMMENTS

We conclude by extracting from the experiments reviewed above some more general observations about reinforcement schedules and their relation to issues in applied behavior analysis.

1. Often, the term *contingency* (or contingencies) is used in applied work or in talking about naturally occurring behavior to describe the interrelations among stimuli, responses, and reinforcers. The term *schedule* is used less often, perhaps because the latter term has come to connote greater precision than *contingencies.* Nonetheless, it is important to recognize that, in the noted uses, the two terms describe the same phenomena. Sometimes contingency is used to describe the fact that the reinforcer depends on a response, but one of us has suggested that *dependency* is preferable for that use (Lattal, 1995; Lattal & Poling, 1981). Terms are important, lest applied behavior analysts consider that they are not studying or using reinforcement schedules. They are—perhaps not with the precise specification of the laboratory, but the schedules are operative nonetheless. This latter observation reinforces our initial observation and the theme of this paper that basic research on reinforcement schedules, even the esoteric ones, is a rich vein for applied behavior analysts to mine.

2. Most basic reinforcement-schedule research has involved and continues to almost exclusively involve positive reinforcement. Positive reinforcement procedures have been meticulously honed over many years by many investigators. Such a history gives behavior analysts a powerful research tool, as the reviewed studies illustrate. At least in part because positive reinforcement procedures are so thoroughly analyzed, reliable, and of such proven value, there has been relatively little study of the aversive control of behavior, involving schedules of negative reinforcement and schedules of punishment. This is an unfortunate omission from the standpoint of applied behavior analysis because the controversies that surround the use

of aversive control in applied settings invite a better basic understanding of aversive control and its by-products (e.g., Iwata, 1987).

3. Reinforcement schedules have not generated the same enthusiasm in applied work as they have at some points in the history of the experimental analysis of behavior. Indeed, many complex schedules have been avoided or regarded as esoteric or even useless by a number of applied behavior analysts. Similarly, Zeiler (1984) reserved his strongest criticism of schedule research for basic researchers who are caught up in the minutiae of schedules. Although these criticisms have merit, each research problem described in the preceding sections suggests exciting adaptations of reinforcement schedules to interesting problems for applied behavior analysts: elucidating the role of behavioral history in current performance, gleaning insights into the relation between verbal and direct contingency control of behavior, and disentangling the dynamic processes that often operate in applied settings.

The questions regarding schedules and schedule use need to be framed functionally and pragmatically rather than structurally: How can the schedule be used to address an important applied question? We earlier noted that at least part of the utility of schedules may result from how the schedule concept is used. Applied, or basic, situations and problems need not, and do not, always reduce down to single, simple schedules. They often can be conceptualized usefully, however, along the lines suggested in some of the experiments on dynamic reinforcement schedules.

4. Reinforcement schedule performance is essential to discussions about mechanisms of reinforcement. For example, in a VR schedule, do high response rates occur because of the differential reinforcement of short interresponse times or because higher response rates increase the overall reinforcement rate? The former position is characterized as molecular and the latter as molar, and each has strong proponents (e.g., Baum, 1973, 1989; Peele, Casey, & Silberberg, 1984). One purpose of Hackenberg and Axtell's (1993) experiment was to determine whether reinforcers operate over extended, molar time frames or whether reinforcement effects are more local.

The body of evidence and the arguments concerning the merits and limitations of each position are beyond the scope of this paper (see Williams, 1983, for an informative critique of the debate), but one general point about the debate is important in relation to applied work. The debate about the mechanisms of reinforcement may be separated from the practical issues of using reinforcement. In applied work, the appropriate level of analysis might be selected on practical grounds alone: One selects a level of analysis that yields the behavioral control necessary to achieve the behavior change. If a molecular approach leads to behavioral control, it should be used. If a molar approach does so, then use it. This is not to undermine the importance and value of understanding reinforcement mechanisms, but only to iterate the idea that many things work even when the precise mechanism of their operation cannot be isolated. For example, Darwin (1859/1964) articulated the theory of natural selection in the absence of any evidence of the genetic mechanisms that make such selection possible.

5. Discussions of both reinforcement schedule performance in the basic literature and reinforcement theory increasingly utilize quantitative description and analysis. Such analyses and their advantages have been summarized succinctly by Nevin (1984) and Shull (1991). Applied behavior analysis has not yet been strongly affected by these developments in the experimental analysis of behavior. Research on the matching law (e.g., McDowell, 1988) and on behavioral momentum (Nevin, Mandell, & Atak,

1983) is grounded in quantitative analysis, but both have been imported into applied behavior analysis primarily at a conceptual level, largely in the absence of the quantitative framework in which they developed.

6. The study of human behavior in the laboratory has largely, but, of course, not exclusively, been a matter of studying schedule control of behavior. Issues of prior histories, both in and out of the immediate experimental situation, and of the role of verbal behavior are common themes in this research. The question of how to study and account for the effects of self-generated rules on human schedule performance is important. It does, however, raise some knotty issues, for if this source of control is acknowledged, we must rethink some fundamental assumptions behavior analysts have made about the ways in which behavior is controlled.

Questions of similarities and differences between human and animal behavior abound. Some attribute much of the difference to procedural differences between human and animal research procedures (Perone et al., 1988), but others view the differences as being more fundamental. The role of rules and instructions in the schedule control of behavior is a critical issue for both basic researchers and applied behavior analysts. Similarly, the more general question of the relation between the controlling variables of animal and human operant behavior cuts to the quick of the relevance of basic research in the experimental analysis of behavior to applied problems.

There was a time in our early history when the study of reinforcement schedules could be considered a distinct area of research, and their elaboration and development was of general concern to many basic researchers. Although research designed to elucidate the effects of schedules of reinforcement still appears regularly in the *Journal of the Experimental Analysis of Behavior,* schedule research is more often conceptualized around other problems than those posed by the reinforcement schedule per se. For example, Hackenberg and Axtell (1993) used a complex schedule to analyze the effects of diminishing returns on behavior, and several investigators have used different schedules as a way of studying problems related to behavioral history. Despite the changed role of schedules in basic research, reinforcement schedules are woven deeply into the fabric of the experimental analysis of behavior. In applied behavior analysis, reinforcement schedules have not sustained the degree of interest that they have among basic researchers. Nonetheless, we hope that our discussion will bring applied behavior analysts to realize that "a student of any problem in psychology . . . ignores the consequences of the precise scheduling arrangements of his experiments [or, we would add, applications] at his peril" (Dews, 1963, p. 148).

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